

CLIMATE LITERACY: The Essential Principles of Climate Sciences

EACH ESSENTIAL PRINCIPLE IS SUPPORTED BY FUNDAMENTAL CONCEPTS COMPARABLE TO THOSE UNDERLYING THE NATIONAL SCIENCE EDUCATION STANDARDS (NSES) AND AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS) BENCHMARKS. CONSULT THE OVERVIEW MATRIX (OPPOSITE) TO INTEGRATE CLIMATE LITERACY INTO YOUR CURRICULUM.

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LIFE ON EARTH HAS BEEN SHAPED BY, DEPENDS ON, AND AFFECTS CLIMATE

- A. The evolution of organisms can be driven by specific climatological conditions, including but not limited to temperature, humidity, precipitation, and sunlight.
- B. Changes in one or more of these climate conditions can produce damaging changes in ecosystems.
- C. Changes in environmental conditions can affect the survival of individual organisms as well as entire species.
- D. Human societies have developed interconnected food, energy, transportation, and socioeconomic systems that take advantage of existing climate conditions and, thus, are vulnerable to climate changes.
- E. Human systems have developed during an unusually stable period in Earth's climate history.
- F. Life on Earth, including microbes, plants, and animals such as humans, can influence climate substantially and has throughout the evolution of life on the planet.

¹ Based on Climate Change: An Information Statement of the American Meteorological Society (adopted by AMS Council on 1 February 2007) Bull. Amer. Met. Soc., 88

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WE INCREASE OUR UNDERSTANDING OF THE CLIMATE SYSTEM THROUGH OBSERVATION AND MODELING

- A. Climate science is based on the assumption that Earth's climate system is understandable and, therefore, that many important aspects are predictable.
- B. Our understanding of climate differs in important ways from our understanding of weather. Thus, climate scientists' ability to predict climate patterns months, years, or even decades into the future is not constrained by the limitations meteorologists face in forecasting weather on much shorter timescales (days to weeks into the future).¹
- C. We gain understanding of climate and how it has changed over time from observational data from weather stations, buoys, satellites, radars, ice and ocean sediment cores, tree rings, cave deposits, native knowledge, and other sources.
- D. Observations, experiments, and theory used to construct and refine computer models and develop scientific explanations lead to better understanding of the linkages between the atmosphere-ocean system and how it relates to the overall climate system's behavior. As a result, more reliable projections of future climate changes will develop over time.
- E. Fundamental characteristics of the climate system have been researched and are understood well enough to make reasonably accurate predictions about the climate system and, therefore, to support decision making, even though research continues into many aspects of climate change.

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THE SUN IS THE PRIMARY SOURCE OF ENERGY FOR THE CLIMATE SYSTEM

- A. Solar energy heats Earth's surface and thus the atmosphere, causing movements of air masses and introducing water in the global water cycle.
- B. Daily variations in solar energy over Earth, caused by the planet's spherical shape, influence many weather and climate processes.
- C. The tilt of Earth on its axis causes solar energy to fall more directly on different parts of Earth during different times of the year, resulting in seasonal changes.
- D. Gradual changes in Earth's orbit around the Sun over tens of thousands of years alter the spatial distribution and intensity of solar energy received on Earth, causing long-term warming and cooling trends, such as ice ages and the warm periods in between them.
- E. Gases in the atmosphere, such as carbon dioxide and water vapor, temporarily trap infrared radiation from the warmed surface of Earth. The additional warmth in the atmosphere created by the greenhouse effect allows liquid water and other life-supporting processes to exist on much of Earth's surface.
- F. Sunlight is the ultimate source of most of the energy used by humans. The energy in fossil fuels such as oil, natural gas and coal comes from energy captured long ago from the sun.
- G. Earth's climate is remarkably sensitive to changes in the planet's energy balance.²



² Hansen, J., Miki, Sato, P., Kharecha, G., Russell, D.W., Lea, and M. Siddall, 2007: Climate change and trace gases. Phil. Trans. Royal. Soc. R, 365, 1925-1954, doi:10.1098/rsta.2007.2052

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EARTH'S WEATHER AND CLIMATE SYSTEMS ARE THE RESULT OF COMPLEX INTERACTIONS

- A. Energy differences within and between the land, ocean, ice cover, and atmosphere result in energy flows that drive weather and climate variations.
- B. Earth's atmosphere, oceans, land, and ice are dynamic, but change at different rates. Significant changes in any of these are likely to influence all other components of the climate system in complex ways.
- C. Water cycling on Earth is fundamental to weather and climate.
- D. The carbon cycle influences climate in a variety of ways, including seasonal interactions between the atmosphere, biosphere, and hydrosphere, and the formation and consumption of fossil fuels. Carbon dioxide, an important greenhouse gas, is removed from the atmosphere in the ocean and other parts of the Earth system through biologic and geologic processes.
- E. Changes in the oceans impact the atmosphere and climate patterns around the globe. In turn, changes in the atmosphere impact the ocean temperatures and currents. The dominant pattern of natural climate variability - ENSO - provides



At sunset over the Pacific Ocean, anvil tops of thunderclouds cast long shadows

an example of the dynamic coupling between ocean and atmosphere.

- F. Circulation in and evaporation of water from the oceans regulate the temperature of Earth. Changes in deep ocean circulation in the past have produced large and rare, abrupt changes in climate.
- G. Relatively small increases in amounts of greenhouse gases—such as carbon dioxide, methane, nitrous oxides and some refrigerants—can magnify the greenhouse effect.
- H. Interactions between components of the Earth's climate system result in changes to the system and produce emergent phenomena unique to the system. Human beings are an integral part of Earth's climate system. Human activities such as fossil fuel burning or deforestation can affect climate and alter the equilibrium of the climate system.

Nansen and Amundsen Basins Observational System (NABOS) 2006 Arctic research expedition aboard Icebreaker Kapitan Dranitsun exploring the possibility that the Arctic Ocean is in transition towards a new, warmer state.

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EARTH'S WEATHER AND CLIMATE VARY OVER TIME AND SPACE

- A. Weather is understood as the atmospheric conditions at any given time or place. Such conditions include temperature, precipitation, humidity, air pressure, cloudiness, and wind speed and direction.
- B. Climate is understood as the atmospheric conditions (i.e., weather variables) averaged over a long period of time



Source: Art Howard, ArtWorks

(season, year, or longer) and over a large area (region, continent, or larger).

- C. Weather and climate variations, such as the seasons or El Niños and La Niñas, can be described by their duration, magnitude or frequency. These variations range from a fraction of a second to many years.
- D. The temperature of a specific place on Earth's surface tends to rise and fall in a somewhat predictable pattern every day and over the course of a year.
- E. Differences in the intensity of sunlight warm Earth's surface and produce daily, seasonal and long-term variations in temperature.
- F. Earth's climate has changed in the past, is currently changing, and is expected to change in the future.
- G. The consensus of scientific opinion is that the natural processes driving Earth's long-term climate changes cannot entirely explain the rapid changes observed in recent decades, nor do they solely predict those projected for coming decades.

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EVIDENCE INDICATES HUMAN ACTIVITIES ARE IMPACTING THE CLIMATE SYSTEM

- A. Human beings are an integral component of Earth's climate system.
- B. Human activities have affected the land, oceans and atmosphere and have altered regional and global climate. These activities include burning fossil fuels, releasing chemicals into the atmosphere, reducing the amount of forest cover, and rapidly expanding farming, development and industrial activity.
- C. Some changes resulting from human activities have decreased the capacity of the environment to support various species.
- D. The increased burning of fossil fuels since the start of the industrial revolution has increased the amount of greenhouse gases in the atmosphere. Because carbon dioxide remains in the atmosphere for many years (hundreds to thousands of years) before being removed by natural processes, this has contributed to Earth's warming.

- E. The preponderance of scientific evidence indicates that the observed increase in global average temperatures since the latter part of the 20th century is very likely due to documented increases in human-induced greenhouse gas concentrations, primarily from the burning of fossil fuels.³
- F. Evidence indicates that changes in many physical and biological systems are linked to human caused warming.⁴



Coal delivered by train to generate electricity

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EARTH'S CLIMATE SYSTEM IS INFLUENCED BY COMPLEX HUMAN DECISIONS INVOLVING ECONOMIC COSTS AND SOCIAL VALUES

- A. Decisions about human activities that affect climate and climate change should involve weighing scientific evidence against uncertainties about future economic growth, energy use, ecosystem integrity, costs and opportunities, probabilities and risks, moral values, and cultural norms.
- B. Identification and understanding of facts and assumptions about climate change are essential to informed decision making to solve related problems.
- C. Climate information can be used to reduce the vulnerability/ enhance the resilience of human communities and ecosystems; the importance of continuing to improve understanding of climate system is crucial.
- D. Industrialization has the potential to improve the quality of life in the short-term but also creates long-term challenges, including increased energy demand and the resultant adverse impacts on ecosystems and the climate system.

³ Based on IPCC 2007: The Physical Science Basis: Contribution of Working Group I

⁴ Based on IPCC, 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II



Agricultural engineers inspect a dry stream

- E. The atmosphere covers the entire surface of Earth; thus, activities that effect climate (e.g., energy use leading to greenhouse gas release into the atmosphere) in one region affect human beings and other species worldwide.
- F. Decisions of one generation both provide opportunities and limit the range of possibilities open to the next generation.
- G. Decisions about energy use and adapting to the effects associated with climate change are made at all levels, from the individual to the global.

- H. Individuals as well as community, government, business and industry leaders can contribute to climate mitigation and adaptation.
- I. Slowing or reversing human impact on climate change trends might be accomplished by combining short-term strategies — such as conservation, more efficient use of resources, and the switch from carbon-intensive energy to renewable sources — with long-term investments in technology research and implementation, and by adopting sustainable development strategies, such as building alternative energy infrastructure and a "green" economy.

FURTHER INFORMATION

For future revisions and changes to this document or to see documentation of the process used to develop this brochure, please visit www.climate.noaa.gov/education. In addition, further information relating to climate literacy and climate resources can be found at: earthobservatory.nasa.gov • www.epa.gov/climatechange • <http://nsdl.org> • www.education.noaa.gov

CLIMATE CHANGES

Throughout Earth's history, climate has changed. Sometimes change has been slow, over centuries and millennia, influenced by changes in the Earth's orbit or movement of tectonic plates. Sometimes change has been abrupt, caused by sudden events such as volcanic eruptions, collisions with meteors or shifts in ocean currents. Organisms and ecosystems have either adapted to the changes or perished.

Earth's climate has influenced human history in profound ways, playing an integral role in whether societies thrive or fail. And we now know that, conversely, human activities -- such as burning fossil fuels and deforesting large portions of land cover -- have a profound influence on Earth's climate. To protect fragile ecosystems and build sustainable communities that are resilient in the face of natural disasters as well as climate change, a climate literate citizenry is essential. This framework for climate literacy identifies the essential principles and fundamental concepts that individuals need to understand in order to make appropriate decisions about human activities that affect the climate now, and to prepare for adaptations to climate change by future generations.

USING CLIMATE AS A TEACHING TOOL

Climate is an ideal interdisciplinary theme for education. At a basic level, climate is a function of the movement of energy, water and carbon through time and space, influenced by air, water, land, ice, and living beings. This complex topic can best be understood by beginning with simple concepts and observations of weather and annual cycles. Students can then build increasingly complex inquiries into the many dimensions of climate: physical, chemical, biological, geographical, social, economic, historical and even technological. As students advance in their learning, this education can equip them to understand the interplay of these factors on the climate and to use this understanding wisely in their personal life and in their role as citizens.

CLIMATE CHALLENGES

Teaching weather and climate is a substantial yet rewarding challenge that crosses numerous academic disciplines. The Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future National Academies report (http://www.nap.edu/catalog.php?record_id=11463)

highlights how the shortage of highly qualified K-12 teachers has forced many of the nation's 15,000 school districts to employ teachers who lack a background in the subject matter that they are asked to teach. Research indicates that some concepts, such as the role of Earth's axial tilt in producing the seasons, and how longer-term orbital fluctuations affect the distribution of solar energy reaching Earth's surface, require a level of cognitive development that make them inappropriate for teaching to younger students. For the youngest students, the forecasts of melting ice caps and the extinction of species can be emotionally overwhelming, producing "eco-phobia" and a sense of paralysis. Despite such concerns, it is nonetheless essential that people of all ages gain an understanding of the science and issues surrounding climate change and an appreciation of their magnitude and significance, so as to make responsible decisions about human activities that influence Earth's climate.

KEY DEFINITIONS

"WEATHER" The atmospheric conditions at any given time or place. Such conditions and others include temperature, precipitation, humidity, air pressure, cloudiness, and wind speed and direction.

"CLIMATE" The atmospheric conditions (i.e., weather variables) averaged over a long period of time (season, year, or longer) and over a large area (region, continent, or larger) as well as the climatic extremes.

"CLIMATE FORECAST" A forecast for how rainfall or temperature in a coming season is likely to be different from climatology (see definition). Climate forecasts are generally based on the chances (or probability) that an event will occur, for example that rainfall or temperature will be either below normal, near normal, or above normal.

"CLIMATE VARIABILITY" The range of values, such as temperature and precipitation, for climate at a particular location can take over time.

"CLIMATE CHANGE" Refers to long-term changes in the climate. Climate change can be natural, or might be caused by changes people have made to the land and atmosphere (e.g., urbanization, pollution).

"CLIMATE SYSTEM" The five physical components (atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere) that are responsible for the climate and its variations.

"LIKELY AND VERY LIKELY" The Intergovernmental Panel on Climate Change defines Likely and Very likely terms to indicate the assessed likelihood, using expert judgment, of an outcome or a result. Virtually certain > 95% probability of occurrence, Extremely likely > 95%, Very likely > 90% and Likely > 60%.

Climate Literacy is an understanding of the climate's influence on you and society and your influence on climate.

DEVELOPING THE GUIDE

This guide is the product of a three-day workshop, Climate and Weather Literacy: Using the AAAS Project 2061 Science Literacy Research to Develop Weather and Climate Literacy Framework, in April 2007. The National Oceanic and Atmospheric Administration (NOAA) sponsored this workshop along with the American Association for the Advancement of Science (AAAS). Organizers included NOAA, NASA Goddard Space Flight Center, and the US Climate Change Science Program's Communications Interagency Working Group; the Department of Commerce and the NOAA Office of Education hosted it. The event was planned and coordinated by Ted Willard, AAAS Project 2061; Frank Nepold, NOAA Climate Program Office; Christos Michalopoulos, NOAA Office of Education; and Jon Wiley, NOAA Office of Education. Principal authors of the guide were Frank Nepold, NOAA Climate Program Office, and Mark S. McCaffrey, Cooperative Institute for Research in Environmental Sciences (CIRES)/University of Colorado-Boulder. All draft and final reports will be posted at NOAA's Climate Program Office's Education site, www.climate.noaa.gov/education/.

The following people also made significant contributions to the development and preliminary review of this guide (for a complete list of please visit <http://www.climate.noaa.gov/education/>).

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First Printing: February 2008

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WHAT IS CLIMATE LITERACY?

You are climate literate if you understand the influence of climate on yourself and society and your influence on climate. A climate-literate person:

- understands the essential principles of all aspects of the earth system governing climate patterns that are presented in this document;
- knows how to gather information about climate and weather, and how to distinguish credible from non-credible scientific sources on the subject;
- communicates about climate and climate change in a meaningful way; and
- makes scientifically informed and responsible decisions regarding climate.

Developed through a community-wide consensus-building process with various members of both the science and education communities they worked to define climate literacy in the United States. Supported through a NOAA Education Grant, the workshop and following efforts brought together individuals representing numerous NOAA offices, other federal science agencies, formal and informal educators, non-governmental organizations, and other vested institutions involved in climate research, education and outreach to work together towards the goal of creating of a framework for climate and weather literacy, building on the research and the science and technology education benchmarks developed by the American Association for the Advancement of Science (AAAS) Project 2061.

The Essential Principles and Fundamental Concepts outlined in this guide (inside) represent ideas that do not fall neatly within a particular discipline. As a result, many Fundamental Concepts illustrate more than one Essential Principle. For example, Essential Principle 1 covers concepts that recocur in other Essential Principles. This is unavoidable and demonstrates the interdisciplinary nature of climate science and informed decision making.

HOW TO USE THIS MATRIX

The overview matrix (right) and the corresponding Essential Principles and Fundamental Concepts chart (inside) identify the climate literacy concepts that meet the NES content standards. The seven Essential Principles run horizontally across the top of the chart, the eight NES content standards and sub-categories run vertically along the far left column. School levels are identified by color (see key below). Identify the appropriate color column, then trace each Standard across the right. From each marked box, follow the column up to find the corresponding Fundamental Concept -- for example, to, b, etc. (Numbers indicate Essential Principles, letters Fundamental Concepts).

Next, refer to the Principles and Concepts chart inside to find a description of the concept.

It is suggested that you view the interactive chart at www.climate.noaa.gov/education

Dotted box = climate aligned to NES content standard

